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RESEARCH-AIRPLANE-COMMITTEE REPORT

ON CONFERENCE ON THE

PROGRESS OF THE X-15 PROJECT

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FLIGHT EXPERIENCE WITH PRESENT RESEARCH AIRPLANES

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INTRODUCTION

The North American X-15 airplane is being designed for speeds and altitudes considerably greater than those presently being encountered by airplanes. In this regard, it might be well to consider the status of flight research with the current research airplanes and see what experience and planned research are pertinent to the X-15 project.

DISCUSSION

Figures 1 and 2 show the regions of Mach number and altitude to be discussed in reference to these present research airplanes. Figure 1 illustrates the envelope of combinations of pressure altitude and Mach number that has been explored to date with the airplanes indicated therein. No one airplane has covered the entire range; for example, the highest altitude and Mach number points were obtained with the Bell X-2 airplane, but the low-speed point at an altitude of 83,000 feet was obtained with the Douglas D-558-II airplane. Figure 2 shows the region of altitude and Mach number which is possible with the X-1 airplanes. Although the recent loss of the X-2 will prevent the investigation of Mach numbers above 3, the X-1E will be able to reach Mach numbers near 2.8. The amount of ballistic flight possible with these airplanes is indicated by the region above the line for $q = 10$ pounds per square foot. The actual amount of this possible region that will be explored cannot be determined at present. Some of the problems that may prevent attaining the entire envelope will be discussed in this report.

Within the envelope already explored, these research airplanes have experienced a number of the problems that are being considered for the much higher performance of the X-15 airplane. Some of the problems encountered with these airplanes are as follows: longitudinal-control effectiveness, high-altitude dynamic stability, thrust misalinement, control at low dynamic pressure, roll coupling, and supersonic directional stability. This listing is not necessarily in the order of the importance of the individual problem.

Several of these problems are illustrated in figure 3 which shows time histories of a flight to the highest altitude yet attained. Low longitudinal-control effectiveness prevented the attainment of a higher altitude by limiting the climb angle. Although all available control was used in the pull-up to climb attitude, only about 1.2g was obtained. Similarly, in the reentry and recovery phase, almost constant full-up control was used, but level flight was not attained until an altitude of nearly 40,000 feet was reached. The pilot was of the opinion that the control was much too weak, the pullout being completed at an uncomfortably low altitude.

This flight resulted in a considerable period of semiballistic flight. Although zero g was not actually reached, a value of normal acceleration of less than 0.1g was maintained for about 50 seconds. The minimum dynamic pressure for this flight was 18.8 pounds per square foot at a pressure altitude of 120,000 feet. In this condition the airplane indicated very poor dynamic stability as shown by the angle-of-attack trace. When the airplane was disturbed by a control application, a pitching oscillation with a period of about 6 seconds and a maximum total angle-of-attack amplitude of about 6° was excited. Although the damping of this motion was extremely low, the oscillation did not annoy the pilot because it produced no appreciable change in normal acceleration and the attitude was still too steep for the pilot to see the horizon. When the peak of the trajectory was attained and the horizon was in view, the pilot was too busy initiating the recovery to bother with attempting to control the longitudinal oscillation. The shortening of the period of increased damping with increasing dynamic pressure is shown in figure 3.

Another problem that has been encountered with current research airplanes and which is of considerable interest in the X-15 project is the matter of thrust misalinement. Figure 4 shows the motions resulting from about a $1/4^{\circ}$ (or 0.7 inch) thrust misalinement for the X-2. Two conditions are shown; one at high-speed medium altitude, the other at the high-altitude and moderate-speed condition shown in figure 3. When the power goes off, the misalinement produces a disturbance in sideslip. The pilot did not object to the disturbance at high Mach number and quickly damped it out. At high altitude, however, he objected to the increased magnitude of the disturbance and the large resulting motions. This condition was considerably more difficult to control; however, the pilot was able to damp the motion and restrict the sideslip motions to small amplitude.

On two occasions with the X-1A airplane, under conditions of low directional stability or extremely high altitude, the disturbance caused by thrust misalinement resulted in loss of control. These occurrences have been reported in reference 1. Figure 4 indicates that engine misalinement can be determined at noncritical conditions and may then be corrected by adjusting the engine in its mount. Misalinement would then result only from the small changes within the engine from flight to flight.

The problem of control at low dynamic pressure when aerodynamic controls are used is being investigated. The lowest dynamic pressure at which flight has so far been performed in the current research program is the 18.8 pounds per square foot previously mentioned. For this condition, the pilot was able to control lateral motions, although the airplane was very unsteady. Plans are to continue this program, utilizing the X-1B and X-1E, to lower dynamic pressure. Analog investigations have indicated that the aerodynamic controls should retain a degree of effectiveness down to a dynamic pressure below 10 pounds per square foot.

Another problem of flight at high altitude is, of course, inertial coupling. The critical average roll rate for divergence is very low at high altitudes as a consequence of the very low magnitude of the aerodynamic restoring moments. The X-2, for example, in the previously cited condition of a Mach number of 1.7 and an altitude of 120,000 feet would experience roll divergence at an average roll rate of 45° per second. Analog studies indicate that the rate of divergence is slow but the low control effectiveness may make it very difficult for the pilot to control the motion. Severe roll coupling has been encountered on the X-1A airplane at an altitude of 90,000 feet and a Mach number of about 2 (ref. 1). In this case the critical roll velocity of about 65° per second was exceeded because of a disturbance produced by thrust misalinement and use of the rudder. Extremely large motions were developed, and control was not regained for about 50 seconds. This occurrence indicates that roll coupling can be of extreme importance, even though the divergence rates are low and high accelerations are not developed.

One of the most important problems of high Mach number flight is the familiar reduction of directional stability as the Mach number is increased supersonically. Figure 5 shows the variation of C_{n_β} at an angle of attack of 0° for some of the current research airplanes. These data were obtained from wind-tunnel investigations and from flight tests. All these configurations would have greatly reduced C_{n_β} at positive angles of attack. The ticks indicate the maximum speeds attained by the various airplanes. All these airplanes except the X-1E have encountered lateral-stability difficulties at supersonic speeds, and the X-1E can be expected to have similar difficulties at high angles of attack. The difficulties ranged from the unstable Dutch roll exhibited by the D-558-II at low angles of attack to the actual directional divergence encountered by the X-1A and the X-2.

The only one of these occurrences which will be discussed in detail is the maneuver that resulted in the loss of the X-2 and the death of Captain Milburn G. Apt, the pilot. Figures 6 and 7 present time histories of various recorded quantities obtained from NACA instruments recovered from the wreckage. Because of light leakage there are gaps in some of the data, as indicated by the dashed lines. Some of the motions were sufficiently large to be off the scale. The data are divided between the two figures in order to avoid confusion. Only a general description of the maneuver was given, and no attempt is made to discuss all the curves.

As the X-2 accelerated to the maximum Mach number, the angle of attack was maintained at less than 1° and had a value of 1° at the maximum Mach number of 3.2. The rudder was locked for supersonic flight. At maximum speed a left turn was initiated by aileron- and stabilizer-control motion that produced a longitudinal disturbance. The pilot had some trouble with this motion but finally was able to control it. In this period the increasing angle of attack decreased the directional stability. Aileron control was gradually moved to neutral, but this movement did not stop the increase of left roll because sideslip had now become positive and the dihedral effect maintained the left rolling moment. The right aileron was then applied to stop the rolling, but aileron yaw caused development of more sideslip. This process continued until finally the airplane diverged sufficiently to develop roll coupling, and the pilot completely lost control.

SUMMARY

In summary, it has been shown that several of the problems of direct pertinence to the X-15 project have been experienced on current research airplanes. The future investigations of the handling qualities of the X-1B and X-1E will furnish additional information. The experiences with the X-1A and the X-2 airplanes are indicative of the extreme caution that is required in this type of flight research. Critical conditions with the X-1B and X-1E will be approached with great care. The X-1B is to be used in investigations of handling qualities at high altitudes and low dynamic pressure. The flights with this airplane will probably not involve Mach numbers much above 2 because of the loss of directional stability. The investigation of control at very low dynamic pressure will be extended to include rocket reaction controls.

Initially, the X-1E program will be to investigate the stability and control characteristics in the Mach number range above 2 and will include means of improving directional stability and handling at high angles of attack. At a later date, the X-1E will be used to extend the low-dynamic-pressure investigation of the X-1A.

REFERENCE

1. Drake, Hubert M., and Stillwell, Wendell H.: Behavior of the Bell X-1A Research Airplane During Exploratory Flights at Mach Numbers Near 2.0 and at Extreme Altitudes. NACA H55G25, 1955.

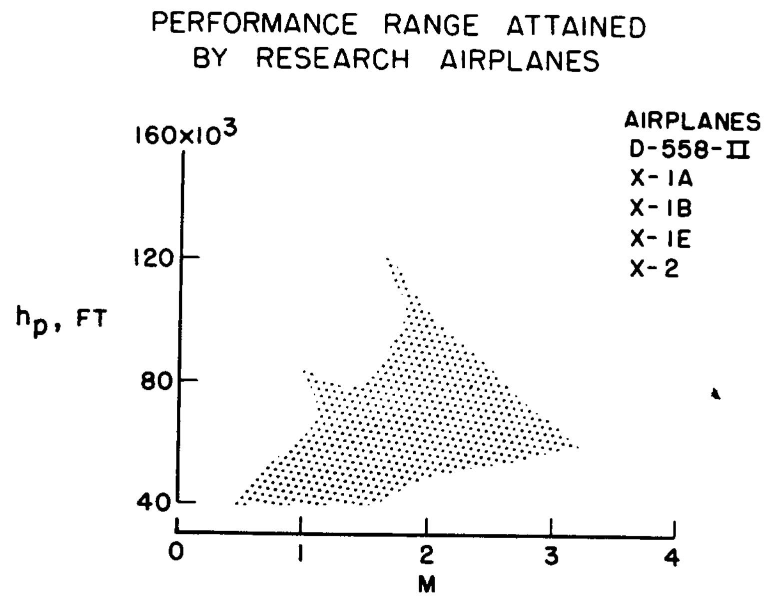

Figure 1

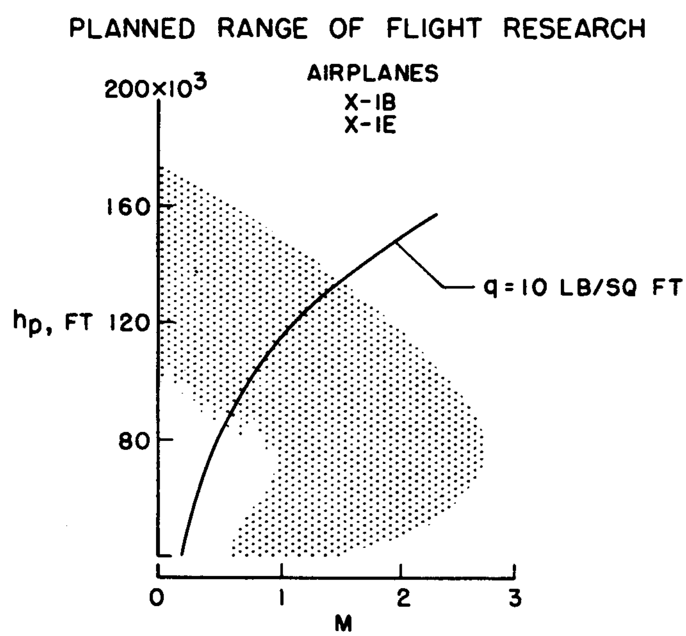

Figure 2

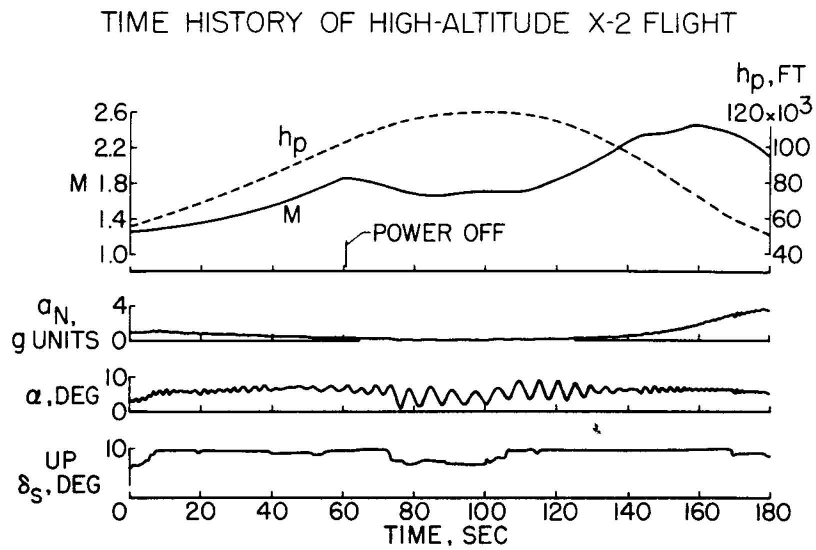

Figure 3

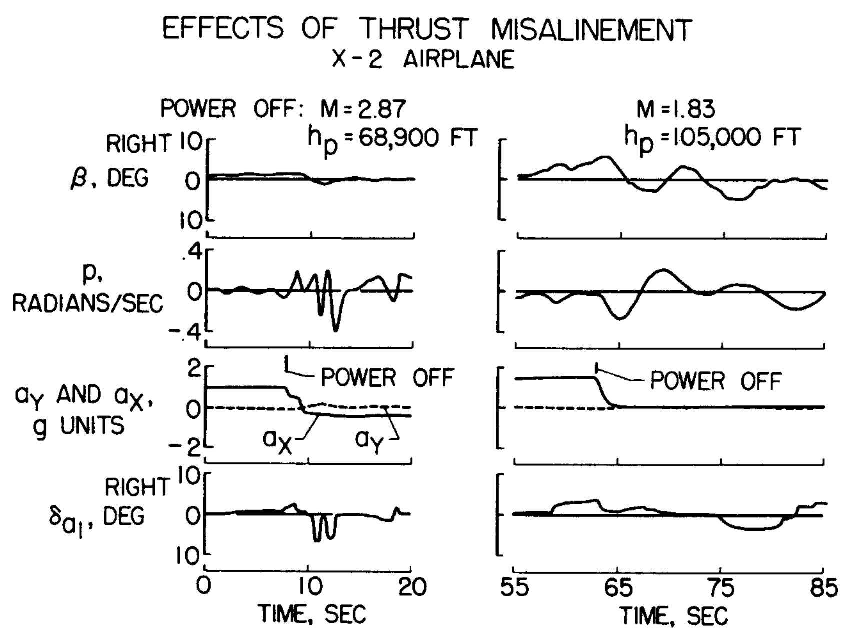

Figure 4

VARIATION OF DIRECTIONAL STABILITY
$\alpha = 0$

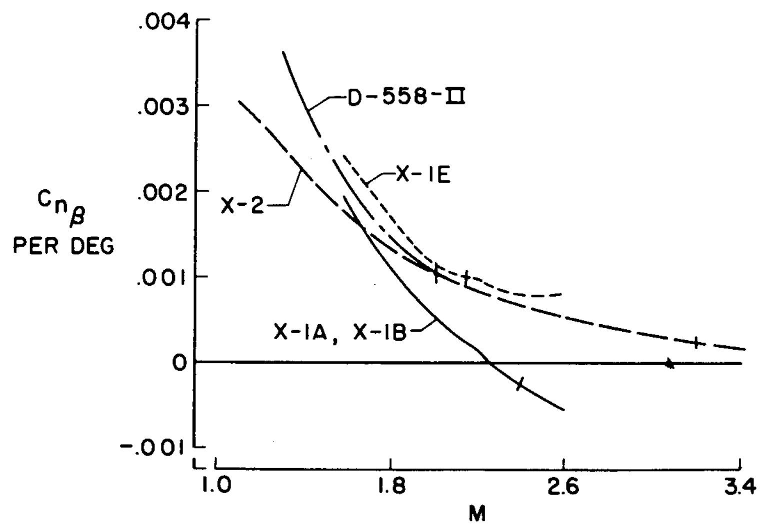

Figure 5

HIGH MACH NUMBER BEHAVIOR OF X-2

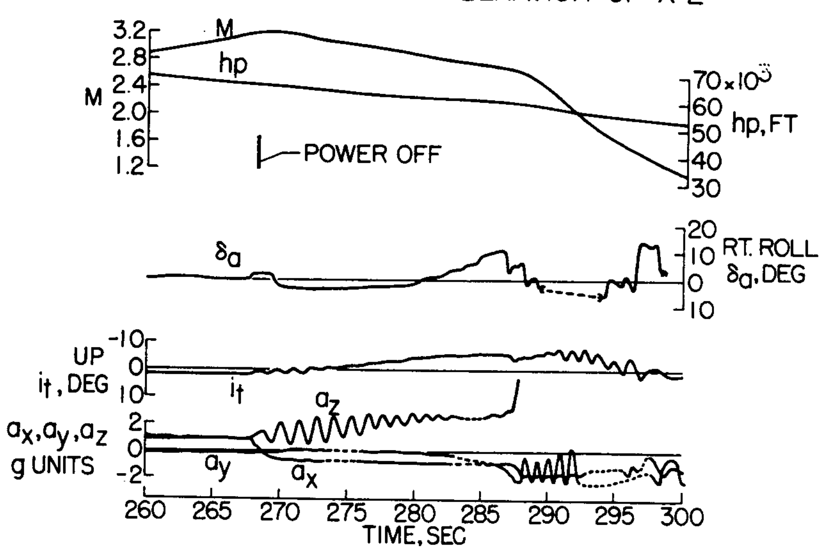

Figure 6

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HIGH MACH NUMBER BEHAVIOR OF X-2

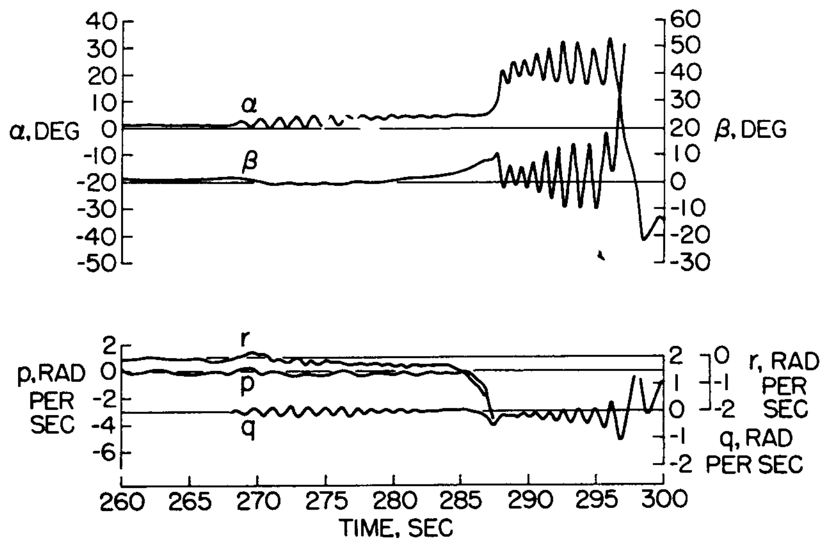

Figure 7

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